

Study of the Natural Radioactivity of Earth Bricks from the Coastal Region, Côte d'Ivoire

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Abstract Building materials are a vital resource for humans due to their widespread distribution throughout the world and their close proximity to local residents. A study of exposure levels to natural radioactivity in earth bricks was conducted in the coastal region of Côte d'Ivoire to assess the effects on the health of the population. To achieve this objective, it was necessary to collect samples of earth bricks for measurement of primordial radionuclide concentrations by gamma spectrometry (GeHP) in the laboratory. This study is the first at the national level to study the radioactivity of earth bricks. The risks were assessed through radiological risk indices, based on the measured activities of natural radionuclides in the samples. The mean activity concentration ranges of ²²⁶Ra, ²³²Th, and ⁴⁰K were 4.11-11.13 Bq.kg⁻¹, 3.10-10.18 Bq.kg⁻¹, and 23.67-266.49 Bq.kg⁻¹, with mean values of 8 Bq.kg⁻¹, 5 Bq.kg⁻¹ and 130 Bq.kg⁻¹, respectively. All mean values of the health risk indices (Ra_{eq}, D_{ex}, D_{in}, AGDE, and AED) were below the limits recommended by ICRP/UNSCEAR. This result indicates moderate exposure for the population, with no significant short-term impact, but should be monitored in the event of prolonged accumulation. The results of this original study provide new information on the radioactivity of building materials in Côte d'Ivoire and worldwide.

Keywords: Côte d'Ivoire, Radionuclides, Health, Earth brick, Gamma spectrometry

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1. Introduction

Natural radioactivity in the built environment is a growing concern in radiation protection, particularly due to its potential impact on the health of chronically exposed populations [1]. Building materials are an integral part of life and are found in all homes. Unfortunately, beyond their great utility, they are recognized as sources of ionizing radiation and therefore pose health risks to human life. Building materials can contain naturally occurring radioactive materials of geological origin that contribute to exposure inside buildings over time. The concentration of radioactivity in building materials can be 10 times higher than the global average for soil [2]. According to the most recent estimates from the United Nations Scientific Committee on the Effects of Atomic Radiation, an average individual receives an effective dose of 2 to 3 mSv each year, nearly 80% of which comes from natural sources, particularly in the home [3]. Long-lived radionuclides such as uranium-238 (²³⁸U), thorium-232 (²³²Th), and potassium-40 (⁴⁰K), as well as their decay

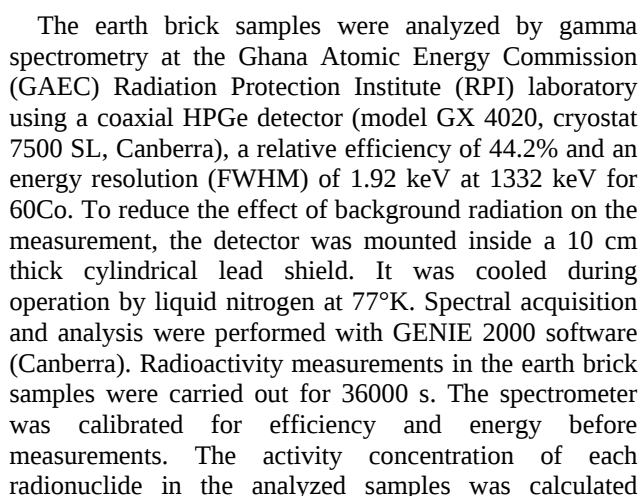
products such as radium-226 (²²⁶Ra), lead-210 (²¹⁰Pb), and radon-222 (²²²Rn), are present in the environment [3]. Humans are exposed to it daily, whether through soil, water, air or building materials. Although this exposure is largely invisible and silent, it constitutes a real risk factor for public health. Among the routes of exposure to natural radioactivity, building materials represent both a direct and indirect source. Direct, through the emission of gamma radiation from the nuclear disintegrations of radionuclides present in the materials themselves. Indirect, through the release of radon, a radioactive gas that can accumulate in poorly ventilated interiors [4]. This dual contribution justifies the growing interest in the study of the radioactivity of building materials, particularly in a context where the search for sustainable and innovative building materials leads to an increasing use of local natural resources or recycled materials. Many studies have established a correlation between prolonged exposure to low doses of radiation and an increased risk of cancer, particularly lung cancer. It is therefore crucial to control the radiological impacts of building materials. Globally, several studies have addressed this issue [5,6,7,8,9]. The demand for bricks in construction in Côte d'Ivoire has

per site from fragments of several bricks. This protocol allowed us to obtain 10 high-quality samples, packaged in situ in sealed polyethylene bags according to their nature and origin.

2.3. Sample Preparation

The treatment consisted of the controlled drying of each sample in an oven at a controlled temperature of 105°C for 12 to 24 hours, depending on the humidity level. This phase resulted in the production of dry samples. These samples were then transformed into powder using an electric grinder, homogenized, and sieved (2 mm) to ensure accurate analysis. After this homogenization phase, a representative portion of each sample was packaged in a container with standardized measuring geometry (Marinelli beakers, SG 500). The containers were hermetically sealed with adhesive tape to prevent the samples from regaining moisture and also to prevent radon gas from escaping. The masses of the prepared samples were measured using a precision electronic balance. The Marinelli beakers containing the samples were stored for 30 days to achieve secular equilibrium between the parent radionuclides and their descendants.

2.4. Measurement of Radioactivity



according to Equation 1:

$$C = \frac{N_{net}}{\varepsilon \cdot P \cdot t_c \cdot m_s} \quad (\text{Equation 1}) \quad [10]$$

Where $C(\text{Bq.kg}^{-1})$ is the activity concentration of the radionuclide considered, $N(\text{net})$ the number of photons measured under the photoelectric peak, ε the detection efficiency of the gamma radiation considered, t_c (s) the measurement time, $m_s(\text{kg})$ the dry mass of samples, p (%) the probability of gamma radiation emission. In this study, the activity concentration of ^{226}Ra is determined using the weighted average of the activity concentrations of its short-lived daughters (^{214}Pb , ^{214}Bi). For ^{232}Th , the activity concentrations of its daughters (^{212}Pb , ^{208}Tl , ^{228}Ac) are used while for ^{40}K , its own line is used. The combined uncertainty on the activity concentration is estimated using equation 2:

$$\Delta C = C \sqrt{\left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta \varepsilon_\gamma}{\varepsilon_\gamma}\right)^2 + \left(\frac{\Delta P_\gamma}{P_\gamma}\right)^2 + \left(\frac{\Delta m_s}{m_s}\right)^2 + \left(\frac{\Delta t_c}{t_c}\right)^2}$$

(Equation 2) [10]

Where ΔC is the uncertainty in the activity concentration of the radionuclide, $\Delta \varepsilon_\gamma$ the uncertainty in the detection efficiency, ΔP_γ the uncertainty in the probability of emission of the gamma ray, Δm_s the uncertainty in the mass of the sample, Δt_c the uncertainty in the measurement time. The minimum detectable activity concentration of each radionuclide is calculated automatically by the Génie-2000 software according to equation 3:

$$AMD = \frac{\sigma\sqrt{B}}{\varepsilon_\gamma \cdot P_\gamma \cdot t_c \cdot m_s} \text{ (Equation 3) [11]}$$

Where $\sigma\sqrt{B}$, ε_γ , P_γ , t_c , m_s are respectively the detection limit (with σ the statistical coverage factor at the 95% confidence level B is the background noise, the detector efficiency (GeHP) at the corresponding gamma energy, the gamma ray emission probability, the measurement time and the dry mass of the sample.

2.5. Calculating Radiological Risks

2.5.1. Equivalent Radium

Equivalent radium allows us to compare the overall gamma effect of the three radionuclides ^{226}Ra , ^{232}Th , and ^{40}K on a basis equivalent to the hazard of ^{226}Ra . Equation 4 was used to calculate this parameter:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \text{ (Equation 4) [12]}$$

2.5.2. Absorbed Dose Rate in Air (D)

In this work, the absorbed dose rate in outdoor air at 1 meter from the ground due to gamma radiation is calculated using Equation 5, where D_{ex} is the absorbed dose rate (nGy.h^{-1}) in outdoor air, C_{Ra} , C_{Th} , and C_K are the activity concentrations (Bq.kg^{-1}) of ^{226}Ra , ^{232}Th , and ^{40}K , respectively, and the factors 0.43, 0.666, and 0.047 are the conversion coefficients (nGy.h^{-1} per Bq.kg^{-1}) of the activity concentrations into dose rates of ^{226}Ra , ^{232}Th , and ^{40}K , respectively.

$$D_{ex} = 0.43.C_{Ra} + 0.666.C_{Th} + 0.047.C_K \text{ (Equation 5) [5]}$$

The absorbed dose rate of gamma radiation in indoor air is calculated from Equation 6, where D_{in} is the absorbed dose rate (nGy.h^{-1}) in indoor air and the factor 1.4 expresses the average ratio between the absorbed dose inside a habitat and the absorbed dose outside a habitat.

$$D_{in} (\text{nGy.h}^{-1}) = 1.4. D_{ex} \text{ (Equation 6) [3]}$$

2.5.3. Annual Effective Dose

Annual effective dose values were evaluated considering outdoor exposures (E_{ex}) and indoor exposures (E_{in}). The total annual effective dose (E) is calculated using Equation 7.

$$AED_T = (D_{ex} F_{ex} + D_{in} F_{in}). T. DCF \text{ (Equation 7) [13]}$$

In this equation, D_{ex} (nGy.h^{-1}) is the absorbed dose rate outside the buildings, D_{in} (nGy.h^{-1}) is the absorbed dose rate inside the buildings, F_{ex} and F_{in} represent the occupancy factors related to the time spent outdoors (0.2) and indoors (0.8) by people, T represents the exposure time in one year (8760h), and DCF (0.7 Sv.Gy^{-1})

is the conversion factor from an absorbed dose to an effective dose.

2.5.4. Annual Gonadal Dose Equivalent (AGDE)

The organs of interest for radiation protection are primarily the gonads, active bone marrow, and bone surface cells due to their radiosensitivity. It is important to specifically assess the annual doses received by these cells. The annual gonadal dose equivalent is estimated using Equation 8:

$$AGDE = 3.09 \text{ CRa} + 4.18 \text{ CTh} + 0.314 \text{ CK} \text{ (Equation 8) [14]}$$

In this equation, AGDE ($\mu\text{Sv.yr}^{-1}$) is the annual gonadal dose equivalent from gamma radiation exposure, CRa, CTh, and CK are the respective activity concentrations (Bq.kg^{-1}) of ^{226}Ra , ^{232}Th , and ^{40}K in the sample, and the factors 3.09, 4.18, and 0.314 are the conversion coefficients ($\mu\text{Sv.yr}^{-1} / \text{Bq.kg}^{-1}$) of ^{226}Ra , ^{232}Th , and ^{40}K , respectively.

3. Results and Discussion

3.1. Activity Concentrations

The statistical summary of the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K measured in the different earth brick samples is provided in Table 1. These concentrations are highlighted in Figure 2. Examination of this figure reveals varying levels of natural radioactivity, reflecting the geological heterogeneity of the raw materials used to manufacture these earth bricks. Indeed, the activity concentrations of ^{40}K are the highest in all samples and range from $23.67 \pm 1.68 \text{ Bq.kg}^{-1}$ to $266.49 \pm 6.54 \text{ Bq.kg}^{-1}$, respectively, in samples BRIR-3 from Bingerville and BRIR-5 from Tabou, with an average value of $129.54 \pm 3.28 \text{ Bq.kg}^{-1}$. This level of radioactivity of ^{40}K can be explained by the presence of clays such as illites which are materials rich in potassium. ^{226}Ra has much lower levels, ranging from $4.11 \pm 0.29 \text{ Bq.kg}^{-1}$ to $11.13 \pm 3.73 \text{ Bq.kg}^{-1}$, observed in the BRIR-6 San-Pedro and BRIR-5 Tabou samples, respectively, with an average of $7.50 \pm 1.02 \text{ Bq.kg}^{-1}$. ^{232}Th activity concentrations were the lowest, ranging from $3.1 \pm 0.93 \text{ Bq.kg}^{-1}$ to $10.18 \pm 0.23 \text{ Bq.kg}^{-1}$ in the BRIR-6 San-Pedro and BRIR-8 Sassandra samples, respectively, with an average of $4.99 \pm 1.12 \text{ Bq.kg}^{-1}$. The second information conveyed by Figure 2 concerns the relative levels of activity concentrations compared to global values. Regarding ^{226}Ra , they are lower than the global average value of 35 Bq.kg^{-1} . In these same samples, the concentrations of ^{232}Th and ^{40}K are also within normal proportions compared to the global average values of 30 Bq.kg^{-1} and 400 Bq.kg^{-1} , respectively. To assess the results obtained, a comparison of the acquired activity concentrations was made with those of other countries, presented in Table 2. Referring to this table, it is noted that the activity concentrations of the radionuclides ^{226}Ra , ^{232}Th and ^{40}K in the earth bricks studied are among the lowest. This shows a low radiological risk for these bricks compared to those of other countries.

Table 1. Activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in earth brick samples

Code	City	Activity concentration (Bq.kg ⁻¹)								
		^{226}Ra			^{232}Th			^{40}K		
BRIR-1	Abidjan	5.77	±	0.3	3.26	±	0.15	110.62	±	3.55
BRIR-2	Abidjan	9.12	±	1.28	3.61	±	0.12	114.55	±	1.85
BRIR-3	Bingerville	4.59	±	0.36	7.97	±	1.91	23.67	±	1.68
BRIR-4	Fresco	6.85	±	1.28	3.49	±	0.29	87.55	±	2.41
BRIR-5	Tabou	11.13	±	3.73	5.24	±	2.75	266.49	±	6.54
BRIR-6	San-Pédro	4.11	±	0.29	3.1	±	0.93	98.1	±	2.23
BRIR-7	Aboisso	10.58	±	0.27	4.53	±	1.6	262.31	±	6.2
BRIR-8	Sassandra	10.94	±	2.02	10.18	±	0.23	191.53	±	3.51
BRIR-9	Dabou	4.93	±	0.25	3.11	±	0.22	116.35	±	1.93
BRIR-10	Dabou	6.95	±	0.37	5.41	±	2.95	24.18	±	2.85
Min		4.11	±	0.29	3.1	±	0.93	23.67	±	1.68
Mean		7.50	±	1.02	4.99	±	1.12	129.54	±	3.28
Max		11.13	±	3.73	10.18	±	0.23	266.49	±	6.54

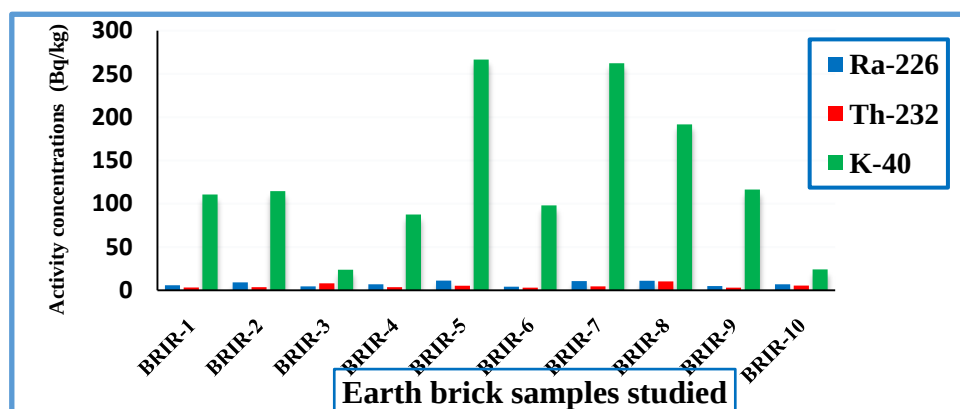


Figure 2. Variation of mean activity concentrations depending on the samples

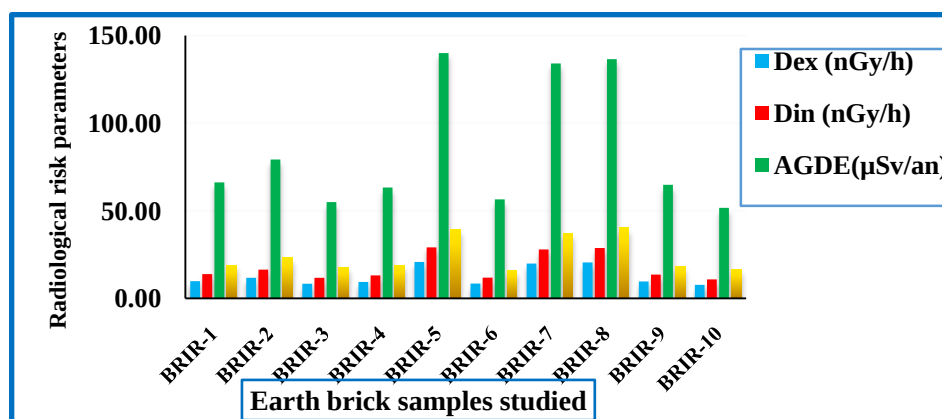


Figure 3. Variation in radiological risk indices by sample

3.2. Health Risk Evaluation

Radiological risk indices were estimated to assess the health risk to the population of the coastal region. Figure 3 shows the variations in radium equivalent, absorbed dose rate, gonadal dose equivalent, and annual effective dose depending on the sample type. According to this figure, radium equivalent values range from 16.10 Bq.kg⁻¹ to 40.25 Bq.kg⁻¹, with an average value of 25 Bq.kg⁻¹, well below the globally accepted maximum value of 370 Bq.kg⁻¹. The minimum Raeq was recorded in BRIR-6 and the maximum in BRIR-8. The outdoor (D_{ex}) and indoor (D_{in}) absorbed dose rates range from 7.73 to 20.80 nGy.h⁻¹ and from 10.82 to 29.12 nGy.h⁻¹, with averages of 12.64

nGy.h⁻¹ and 17.69 nGy.h⁻¹, respectively. The annual gonadal dose ranges from 51.68 $\mu\text{Sv.yr}^{-1}$ to 139.97 $\mu\text{Sv.yr}^{-1}$, with an average of 84.70 $\mu\text{Sv.yr}^{-1}$ below the guideline value of 415.65 $\mu\text{Sv.yr}^{-1}$. When considering the dosimetric impact of these materials on occupants, the annual effective dose ranges from 0.06 mSv.yr⁻¹ to 0.17 mSv.yr⁻¹ depending on the samples. These values would expose a person to an average effective dose of 0.1 mSv.yr⁻¹, which represents 10% of the limit of 1 mSv.yr⁻¹ set by the ICRP. In view of the various results obtained, it appears that the various health risk indices relating to the primordial radionuclides ^{226}Ra and ^{232}Th , and ^{40}K are all non-zero but low compared to their global counterparts. However, from a radiation protection point of view, the low level of a risk index does not necessarily imply a lack of danger because

any dose of ionizing radiation has the potential to harm health, especially in vulnerable groups such as children and pregnant women. This low level of exposure therefore requires vigilance, continuous monitoring and, if possible, corrective measures, in order to minimize any potential impact on human health.

Table 2. Comparison of average activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in earth brick samples from different countries

Countries	Construction materials	Activity concentration (Bq.kg^{-1})			References
		^{226}Ra	^{232}Th	^{40}K	
Algeria	Earth brick	65	51	675	[15]
Jordan	Earth brick	33	37	511	[16]
Germany	Earth brick	59	67	673	[17]
Norway	Earth brick	104	62	1058	[17]
Brazil	Earth brick	51.7	65.3	747	[18]
(EUC)	Earth brick	50	50	670	[19]
Malaysia	Earth brick	9.16	10.45	92.87	[20]
Ghana	Earth brick	26.9	17	359.2	[21]
Cameroon	Earth brick	49.6	91	172	[22]
Côte d'Ivoire	Earth brick	7.5	4.99	129.54	Our study

4. Conclusion

This study focuses on the radiological characterization of local building materials and the assessment of external exposure doses associated with their use. Analyses conducted using gamma spectrometry quantified the activity concentrations of pre-existing radionuclides, notably ^{226}Ra , ^{232}Th , and ^{40}K . The results, which are below the normative thresholds, confirm their safe use for the majority of the samples studied. Beyond the scientific aspect, this study is of major socioeconomic interest. It will help fill a significant gap in knowledge of the radioactivity levels of local materials in Côte d'Ivoire and provide essential elements for protecting the health of populations. This work will continue with other types of building materials for the future development of appropriate national standards and to promote better consideration of radiation protection in local construction.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] UNSCEAR (1993). Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations Publication, New York, USA.
- [2] Baha, A., Hashim, S., Sanusi, M. S. M., & Chik, E. M. F. E. (2025). Radiological impact of natural radioactivity in Malaysian building bricks. *Radiation Physics and Chemistry*.
- [3] UNSCEAR (2000). Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes. United Nations, New York.
- [4] Koua, A., H. Michel, J. Alabdullah, V. Barci, H.K. Aka, G. Barci-funel and G. Ardisson, 2009 a. First measurements of anthropogenic and natural radionuclides in surface soils (10 cm) of Côte d'Ivoire. *Compt. Rendus de l'Academie des Sci.*, 12 (8): p 850-855.
- [5] Shams, A Issa M, Alaseri SM. (2015). Determination of natural radioactivity and associated radiological risks in bulding materials used in Tabuk Area. *Saudi Arabia.Int.J. Adv.Sci.Technol.* 82: p 45-62.
- [6] F.Etoo, O.Adupko, E. Darko, G.Emi-Reynolds, A.Awudu, H. Ahiamandjie, J .Tandoh, F.Hasford, S. Adu et O.Gyampo, (2011). "Assesment of natural radioactive materials in bulding materials used along the coast of central region of Ghana" *Research Journal of Environmental and Earth Sciences*, vol 3, n°13, p 261-268.
- [7] Righi,S. and Bruzzi, L. (2003), Natural Radioactivity and Radon Exhalation in Building Matériaux Used in Italian Dwellings. *Journal of Environmental Radioactivity*, 88, p 158-170.
- [8] Monnehan G. Alain. Gogon B. D. L. Huberson. Braffo A. Florentin. Djagouri Koudou. Koua A. Antonin. Kouakou Omer (2019). Assesment of equivalent radium and annual effective dose due to building matériaux in Côte d'Ivoire by gamma spectrométry: cases of cement. *Journal of applied sciences*, 9, p 774-783.
- [9] Brigui JC, Gogon BD. Djagouri K, Monnehan GA, Penabei S. Determination of natural radioactivity and health risks of cement in Abidjan District, Côte d'Ivoire, *Radiat Prot Environ* 2023; 46: 53-9.
- [10] Darko, E.O. Faanu, A.,Razak,A.,Emi-Reynolds,G., Yeboah,J., Oppon,O.C. , Akaho, E.H.K. (2010).Public exposure hazards associated with natural radioactivity in open pit mining in Ghana. *Radiation Protection Dosimetry*, 138 (1), p 45-51.
- [11] Curie, L.A., (1968). Limits for qualitative detection and quantitative determination. *Anal. Chem.*, 40: 586-593.
- [12] Beretka, I, Mathew P.I, (1985). National radioactivity of Australian building materials waste and products. *Health Phys.* 48, p 87-95.
- [13] Mahmoud pashazadeh A, Aghanjani M, Nabipour I, Assadi M. (2014). Annual effective dose from environmental gamma in Bushehr city. *J.Environ. Health Sci. Eng.* 12: 4.
- [14] Tufail, M. Nasim, A. and waqas, M. (2006) Measurement of Terrestrial Radiation for Assessment of Gamma Dose from Cultivated and barren Soils of Faisalabad in Pakistan. *Journal on Radiation Measurement*, 41, p 443-451.
- [15] Amrani D, Tahtat M. (2001). Natural radioactivity in Algerian building materials. *Appli. Radiat. Isot.* 54: p 687-689.
- [16] Ahmad N., Matiullah J. and Hussein A. J.A., (1998). "Natural radioactivity in Jordanian soil and bulding materials and the associated radiation hazards", *Journal of Environmental Radioactivity*, Vol.39 N°.1, p 9-22.
- [17] NEA-OECD, (1979). Exposure to radiation from natural Radioactivity in building materials"; Report by NEA of experts of the Nuclear Energy Agency. OECD, Paris, France.
- [18] Malanca A. and Gaidolfi L., (1996). "Preliminary radiological surey in some towns of the northeastern Brazilian wilderness", *Nucleus Journal*, Vol.33, N°.3, pp.139-144.
- [19] EC (1999). Radiological Protection Principes Concerning the Natural Radioactivity of building Material.
- [20] Aboubakr Mohamed Helal Mohamed. (2018). Natural radionuclides in building materials and assessment of indoor radon concentration in USM. Thesis for the degree of Master of Science. July.
- [21] F. Otoo, E.O. Darko, M. Garavaglia, C. Giovani, S. Pividore, A.B. Andam, J.K. Amoako, O.K. Aduko, S. Inkoom, S. Adu. (2018). Public exposure to natural radioactivity and radon exhalation rate in construction materials used within Greater Accra Region of Ghana.
- [22] Ngachim, M. Garavaglia, C. Giovani, M.G. Kwato Njock, A. Nourreddine. (2007). Assessment of natural radioactivity and associated radiation hazards in some Cameroonian bulding materials, *Radiat.Meas.* 42, p 61-67.

